ISSN 2229-5518

PULSE DURATION MODULATION BASED INDUCTIVE (PDM) LINKS FOR WIRELESS POWER TRANSFER SYSTEM

EZEKIEL NNAMERE ANEKE[1], PROF. E.N.C OKAFOR[2], DR DAMIAN NNADI[3]

[1]Ph.d Scholar, [2]SUPERVISOR, [3]CO-SUPERVISOR

Department of Electrical and Electronic Engineering

ESUT, Enugu Nigeria.

ENG.Ezekiel.Aneke@ieee.org, encokafor2000@yahoo.com, damian.nnadi@unn.edu.org

Abstract: Wireless power transfer system (WPT) is a technology that transports electric energy to another location without physical wires. It is a good idea to wirelessly transmit electricity especially where it is inconvenient, impractical, hazardous, or impossible to reach, but the method at which the electric power is being transmitted is most important factor of wireless power transmission. Energy should be transmitted with power losses and interference with other electronic devices which required a Pulse duration modulation. Pulse duration modulation (PDM) based inductive links for wireless power transfer system is a novel innovation in wireless power transmission. Several techniques and technologies has been used in the past for wireless power transfer but none of the techniques uses PDM or pulse width modulation (PWM) which offer a fast switching that can easily be controlled or manipulated via feedback networks. The longer the switch rate of PDM compared to the off periods can determine the efficiency and total power supplied to an inductive link. PDM as one of the principal algorithms used in power inverters and photovoltaic system for maximum power point tracking and here it offers the best technique for adequate power output at the receiver end of wireless power transmission system. Since efficiency plays an important role in the design of wireless power transfer so the introduction of PDM makes a significant contribution to knowledge for eliminating power loss in WPT switching techniques.

Introduction:

Wireless power transfer (WPT) system is a technology and technique for the transmission of electric energy from an AC or DC power source to an electrical load without the use of discrete man-made conductors. Once being powered, field energy can be conveyed across an intervening space to one or more receivers where the energy will be converted back to an electrical current and then be utilized. The process involves time-varying electric, magnetic or electromagnetic fields, a concept that has been around since the beginning of the 20th century, when Nikola Tesla first thought of it. Using Tesla coil to create alternating and extremely high potential differences between two pieces of metal, an electric field would be alternating back and forth releasing energy to be captured by a receiver. This idea has being giving birth to several other concepts and technologies today which has been incorporated or developed for different applications such as RFID, rollable and foldable displays, medical implants, rechargeable electric toothbrush (www.oralb.co.u.k), portable inductive power station, wireless mobile phone charging and induction heaters, etc. The main interest of engineers in wireless power transmission today is 'efficiency' regardless of the system power transmission range. Power transfer efficiency (PTE) and power delivered to the load (PDL) are two key parameters in wireless power transfer inductive links system. This affects the energy source specifications, heat dissipation, power transmission range, and interference with other devices. To improve the PTE, a pulse duration modulation (PDM) based inductive links for wireless power transfer system has been developed for today's inductive links design and optimization.

This paper present a pulse duration modulation (PDM) based inductive links for wireless power transfer system which is a novel innovation in wireless power transmission. Several techniques and technologies has been used in the past for wireless power transfer but none of the techniques uses PDM or pulse width modulation (PWM) which offer a fast switching that can easily be controlled or manipulated via feedback networks. With a PDM and feedback controls, the long switching rate of PDM compared to the off periods can determine the efficiency and total power supplied to an inductive link. PDM as one of the principal algorithm used in pure sine wave inverters and photovoltaic system for maximum power point tracking which as well can offers the best technique for adequate power output at the receiver end of wireless power transmission system. This technique is a viable and cost-effective method that encodes information for transmission and allows the control of the power supplied to the inductive link system. Wireless implantable microelectronic devices (IMDs) are good examples of where power and data transmission links can be used effectively encoded, transmitted and received wirelessly across the skin barrier since breaching the skin with interconnect wires would be a source of morbidity for the patient and significantly increases the risk of infection.

According to 'Wireless Power and Data Transmission to High-performance Implantable Medical Devices' By Mehdi Kiani, 2014, there are three major techniques for wireless power transmission to IMDs:

- Ultrasound power transmission,
- High-frequency electromagnetic-wave transmission,
- And Inductive-coupling power transmission.

None of these techniques uses PDM or pulse width modulation (PWM) for fast switching and voltage control. There is also a need to minimize energy consumption because energy consumption often restricts functionality in many electronics applications. The main advantage of PDM is that power loss in the inductive links is very low. When a switch is off there is practically no current, and when it is on and power is being transferred, there is almost no voltage drop across the switching transistors. Power loss, being the product of voltage and current, is thus in both cases close to zero.

Objective:

The objective of this work was to develop a novel technique for high-performance wireless power transmission using PDM which is beneficial for powering electronic devices such as biosensors and neural recording/stimulation devices, smartcards, radio-frequency identification (RFID), near-field communication (NFC), wireless speakers, wireless sensor networks, electric vehicles and wireless charging mobile devices.

A short range PDM based wireless energy transfer for inductive links system.

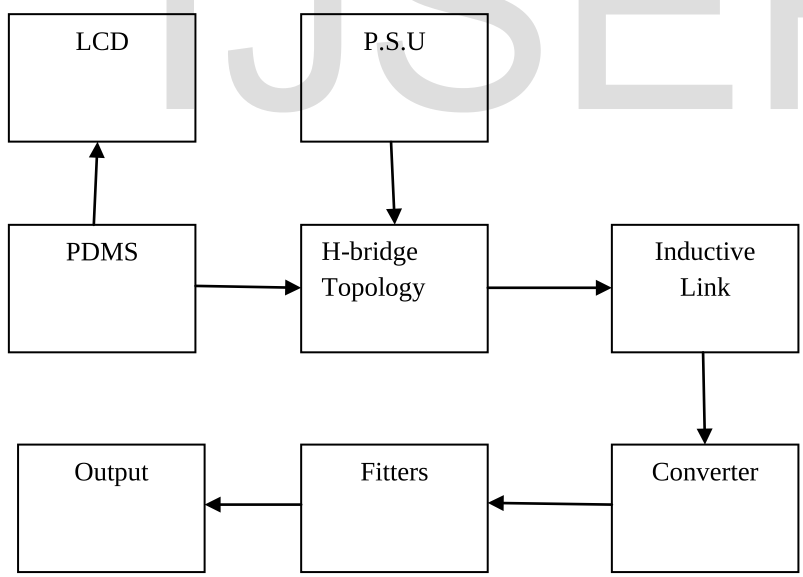
To design a circuit that can result in a better performance and high operating efficiencies for inductive power transfer system.

Design methodology:

An 8-bit Microcontroller Based Control Circuit was used to generate a 'high frequency Pulse Duration Modulation Sine Wave' (PDMS) or Sinusoidal PWM. This oscillating high frequency PDMS are fed to four switching power transistors that form H-bridge Topology. The H-bridge is used to drive an inductive link known as the transmitter coil, through which an efficient power can be transmitted to the receiver coil with harmonic distortion less than 3%

At the receiver coil, the output circuit consists of converters and filters were connected to convert back the induced oscillating field energy to DC power. The average value of voltage and current fed to the transmitter coil is controlled by turning the H-Bridge switching transistors between supply and the transmitter coil ON and OFF at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied by the inductive link.

PDMS is a type of "carrier-based" pulse width modulation. Carrier based PWM uses pre-defined modulation signals to determine output voltages. In sinusoidal PWM, the modulation signal is sinusoidal, with the peak of the modulating signal always less than the peak of the carrier signal. The system block diagram is shown below:



The system consists of a complex units grouped in two parts:

- Microcontroller based PDMS Generator unit
- LCD Unit

- H-bridge Power transistor unit
- Inductive Link Unit
- Power Conversion unit.
- Fitter unit

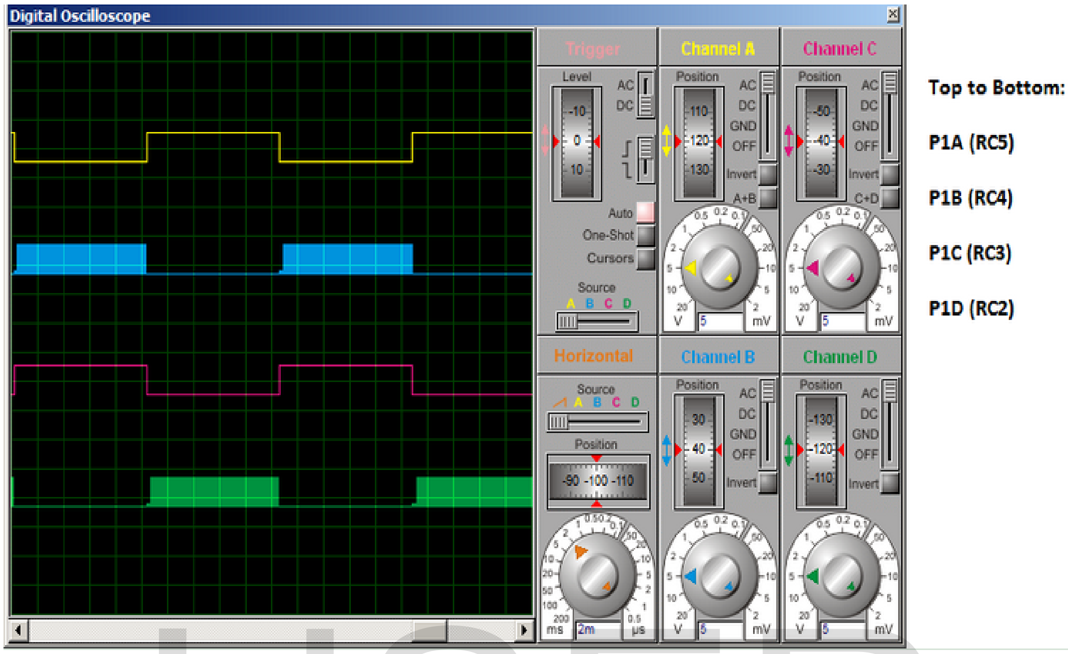
The block diagram is the overall system architecture before it was simulated in the computer using ISIS Protues Professional software. A live experiment was done on various section or units of the system circuits for a better analysis of the inductive link system.

In the microcontroller based PDMS Generator unit, a sine table was used to generate a sine wave using a PIC16F684. The 16F684 run on 16MHz crystal oscillator and use a 16 kHz switching frequency. So, the required value of PR2 is 249. The sine table (for half a cycle) is: 0, 25, 49, 73, 96, 118, 139, 159, 177, 193, 208, 220, 231, 239, 245, 249, 250, 249, 245, 239, 231, 220, 208, 193, 177, 159, 139, 118, 96, 73, 49, 25.

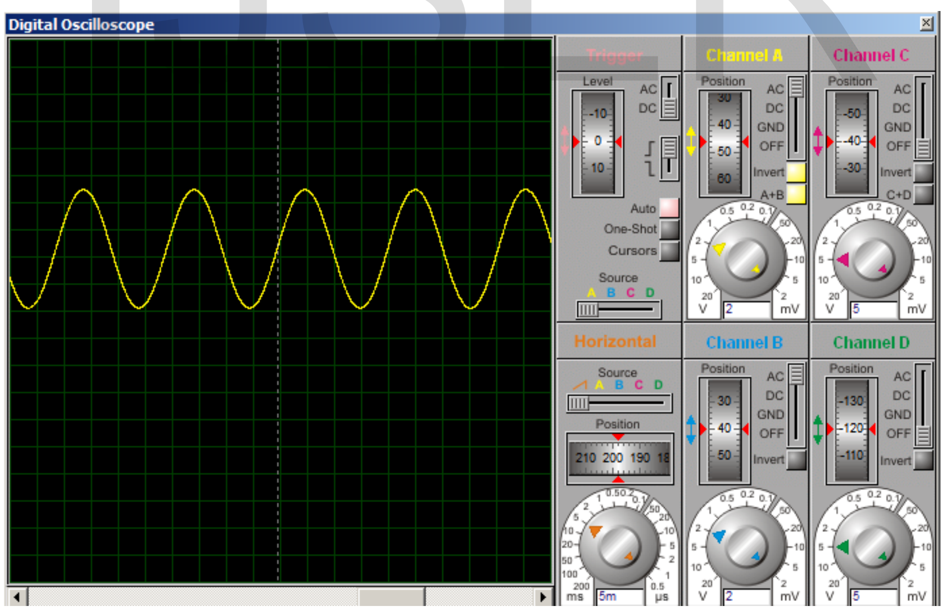
Table pointers were used and the frequency was set to 50Hz while the switching frequency is 16 kHz. The 16F684 generates SPWM signals on P1A, P1B, P1C and P1D pins which should then be connected to a full-bridge stage for feeding into the inductive link coils.

16 kHz frequency is used since it is toward the end of the audible spectrum and so the noise emitted will not be intolerable. Frequency above 20 kHz is not used as 20 kHz is the maximum frequency for the ECCP module of 16F684. Since the ECCP module and interrupt take care of the SPWM, it is being executed by the hardware modules. So, while these are running, the LCD tasks were done in the while (1) loop, since no other task is being carried out besides SPWM.

The system were designed and simulated on Protues and the practical experimentation of the hardware in the electronic lab. The resulting waveforms are shown below:



The SPWM signals



The generated sine wave after filtration

Design consideration:

PIC16F684 was chosen because it is a little 14-pin PIC that contains all that is needed for SPWM (sinusoidal pulse width modulation) – the ECCP module. Since the ADC, comparator or other peripherals are not used, there are enough pins available to be used in the PIC16F684.

The switching frequency has to be much higher than what would affect the inductive links which is to say that the resultant waveform perceived by the links must be as smooth as possible. The rate (or frequency) at which the power supply must switch can vary greatly depending on load and application.

System source code:

```
unsigned char sin_table [32]={0,25,49,73,96,118,137,
159,177,193,208,220,231,239,245,249,250,249,245,
239,231,220,208,193,177,159,137,118,96,73,49,25};



unsigned int TBL_POINTER_NEW, TBL_POINTER_OLD, TBL_POINTER_SHIFT,
SET_FREQ;
unsigned int TBL_temp;
unsigned char DUTY_CYCLE;
```

```
void interrupt(){

if (TMR2IF_bit == 1){

TBL_POINTER_NEW = TBL_POINTER_OLD + SET_FREQ;

if (TBL_POINTER_NEW < TBL_POINTER_OLD){

CCP1CON.P1M1 = ~CCP1CON.P1M1; //Reverse direction of full-bridge

}

TBL_POINTER_SHIFT = TBL_POINTER_NEW >> 11;

DUTY_CYCLE = TBL_POINTER_SHIFT;

CCPR1L = sin_table[DUTY_CYCLE];

TBL_POINTER_OLD = TBL_POINTER_NEW;

TMR2IF_bit = 0;

}

}


void main() {

SET_FREQ = 410;

TBL_POINTER_SHIFT = 0;

TBL_POINTER_NEW = 0;

TBL_POINTER_OLD = 0;

DUTY_CYCLE = 0;
```

```
ANSEL = 0; //Disable ADC

CMCON0 = 7; //Disable Comparator

TRISC = 0x3F;

CCP1CON = 0x4C;

TMR2IF_bit = 0;

T2CON = 4; //TMR2 on, prescaler and postscaler 1:1

while (TMR2IF_bit == 0);

TMR2IF_bit = 0;

TRISC = 0;

TMR2IE_bit = 1;

GIE_bit = 1;

PEIE_bit = 1;


while(1);

}
```


PERFORMANCE AND System ANALYSIS implemented in the Electronic Lab:

ISSN 2229-5518

Practical experimental realization of the system

The system was programmed and simulated with a computer based simulation softwares known as ISIS Professional Proteus and Design software programs was programmed using Mikro C pro for Peripheral Interface Controller. The experimental realization of the scheme consists of two coils that are tuned at the same frequency. An oscillating circuit is connected with a source coil referred here as the transmitter coil which is coupled resonant inductively to an intermediate coil Q; that is in turn coupled resonant inductively to a load carrying coil R. The coils are made of an electrically conducting copper pipe of cross-sectional radius a wound into a helix of single turn, radius r. The inductive coupling was 6mm enameled copper wire (Magnet wire) for constructing the transmitter coils which has a thin layer of insulation coatings on it. The transmitter coil is constructed with a diameter of 16.5cm or 6.5 inches and 8.5 cm of length. The equation for finding the inductance of a single layer air core coil is given below.

$$L = 0.001 N2 (a/2)2 / (114a + 254l) H$$

Now we are applying the desired values for the coil,

$$L = 0.001\times22\times (0.165/2)2 / ((114\times0.165) + (254\times0.085))\ H$$

$$L = 0.674\ \mu H$$

The receiver coil was constructed using 18 AWG copper wire having diameter of 8cm.The equation for finding the inductance of a single layer air core coil is given below.

$$L = 0.001\ N2\ (a/2)2 / (114a + 254l)\ H$$

Now we are applying the desired values for the coil,

$$L = 0.001\times32\times (0.08/2)2 / ((114\times0.08) + (254\times0.01))\ H$$

$$L = 1.235\ \mu H$$

Due to various limitations in PIC16, such as ADC speed, instruction time and the ALU, it is extremely difficult, if not impossible, to calculate in real time the values required for feedback in sinusoidal pulse width modulation (SPWM). Thus, to implement feedback, a different approach must be used. That approach would be to retrieve the values from a sine table that contains the duty cycle values for a specific duty cycle. The duty cycle sine table is:

const unsigned char sin_table[416]={

0, 16, 32, 47, 62, 77, 91, 103, 115, 126, 136, 144, 151, 156, 160, 162, 163, 162, 160, 156, 151,

144, 136, 126, 115, 103, 91, 77, 62, 47, 32, 16, //65%

0, 17, 33, 49, 65, 80, 94, 107, 120, 131, 141, 149, 156, 162, 166, 168, 169, 168, 166, 162, 156, 149, 141, 131, 120, 107, 94, 80, 65, 49, 33, 17, //67.5%

0, 17, 34, 51, 67, 82, 97, 111, 124, 135, 146, 154, 162, 167, 172, 174, 175, 174, 172, 167, 162, 154, 146, 135, 124, 111, 97, 82, 67, 51, 34, 17, //70%

0, 18, 35, 53, 69, 85, 101, 115, 128, 140, 150, 160, 167, 173, 178, 180, 181, 180, 178, 173, 167, 160, 150, 140, 128, 115, 101, 85, 69, 53, 35, 18, //72.5%

0, 18, 37, 55, 72, 89, 104, 119, 133, 145, 156, 166, 174, 180, 184, 187, 188, 187, 184, 180, 174, 166, 156, 145, 133, 119, 104, 89, 72, 55, 37, 18, //75%

0, 19, 38, 56, 74, 91, 108, 123, 137, 150, 161, 171, 179, 186, 190, 193, 194, 193, 190, 186, 179, 171, 161, 150, 137, 123, 108, 91, 74, 56, 38, 19, //77.5%

0, 20, 39, 58, 77, 94, 111, 127, 141, 155, 166, 176, 185, 191, 196, 199, 200, 199, 196, 191, 185, 176, 166, 155, 141, 127, 111, 94, 77, 58, 39, 20, //80%

0, 20, 40, 60, 79, 97, 114, 131, 146, 159, 171, 182, 190, 197, 202, 205, 206, 205, 202, 197, 190, 182, 171, 159, 146, 131, 114, 97, 79, 60, 40, 20, //82.5%

0, 21, 42, 62, 82, 100, 118, 135, 151, 165, 177, 188, 197, 204, 209, 212, 213, 212, 209, 204, 197, 188, 177, 165, 151, 135, 118, 100, 82, 62, 42, 21, //85

0, 21, 43, 64, 84, 103, 122, 139, 155, 169, 182, 193, 202, 210, 215, 218, 219, 218, 215, 210, 202, 193, 182, 169, 155, 139, 122, 103, 84, 64, 43, 21, //87.5%

0, 22, 44, 65, 86, 106, 125, 143, 159, 174, 187, 198, 208, 215, 221, 224, 225, 224, 221, 215, 208, 198, 187, 174, 159, 143, 125, 106, 86, 65, 44, 22, //90%

0, 23, 45, 67, 88, 109, 128, 147, 163, 179, 192, 204, 213, 221, 227, 230, 231, 230, 227, 221, 213, 204, 192, 179, 163, 147, 128, 109, 88, 67, 45, 23, //92.5%

0, 23, 46, 69, 91, 112, 132, 151, 168, 184, 198, 210, 220, 228, 233, 237, 238, 237, 233, 228, 220, 210, 198, 184, 168, 151, 132, 112, 91, 69, 46, 23 //95%

//0, 25, 49, 73, 96, 118, 139, 159, 177, 193, 208, 220, 231, 239, 245, 249, 250, 249, 245, 239, 231, 220, 208, 193, 177, 159, 139, 118, 96, 73, 49, 25, //100%

};

Each set of values corresponding to one duty cycle has 32 values. A table pointer is used to retrieve the values for a given duty cycle. So, when the value of the table pointer is 0, the program reads the first 32 values (65% duty cycle), then the next 32 values when value of table pointer is 1 and so on. The microcontroller first starts with the lowest duty cycle and then analyses the output voltage. If the output voltage must be increased, the value of the table pointer is incremented and so, the next set of values is retrieved, increasing duty cycle and thus output voltage. If output voltage must be decreased, the value of the table pointer is decremented so that the previous set of values is retrieved, lowering duty cycle and thus output voltage. The table pointer code are:

```
FBV = ADC_Get_Sample(FBCh);
if (FBV < 512)
{
FB_Step++;
if (FB_Step > 12) FB_Step = 12;
}
Else
{
if (FB_Step > 0){
FB_Step--;
}
}
adder = FB_Step << 5;
TMR1L = 0;
```

International Journal of Scientific & Engineering Research, Volume 7, Issue 9, September-2016
ISSN 2229-5518

```
TMR1H = 0;

T1IF_bit = 0;
```

The reference value of the ADC is 5V, so 512 represent a voltage of 2.5V, which is the feedback reference voltage. When voltage on ADC pin is >2.5V, table pointer value is decremented and when it is <2.5V, table pointer value is incremented.

The required set of values is retrieved and applied like this:

Code:

```
TBL_POINTER_NEW = TBL_POINTER_OLD + SET_FREQ;
if (TBL_POINTER_NEW < TBL_POINTER_OLD){
  P1M1_bit = ~P1M1_bit;
}
TBL_POINTER_SHIFT = TBL_POINTER_NEW >> 11;
DUTY_CYCLE = TBL_POINTER_SHIFT + adder;
CCPR1L = sin_table[DUTY_CYCLE];
TBL_POINTER_OLD = TBL_POINTER_NEW;
TMR2IF_bit = 0;
```

CONCLUSION

PDM Wireless transmission is useful in cases where instantaneous or continuous energy transfer is needed. After analyzing the whole system step by step for optimization, a PDM based wireless power transfer system via magnetic resonant coupling system was designed and implemented. Experimental results showed that significant improvements in terms of power-transfer efficiency have been achieved. It is described and demonstrated that magnetic resonant coupling can only deliver short range power wirelessly from the source coil to the receiver coil with capacitors at the coil terminals providing a simple means to match resonant frequencies for the coils. This mechanism is a potentially robust means for delivering wireless power to a receiver from a source coil.

Reference

1. Russell M Kerchner and George F Corcoran, "Alternating-Current Circuits", pg. 273-324, 1960.
2. Songping Mai, Chun Zhang, Mian Dong, Zhihua Wang, "A Cochlear System with Implant DSP", Proceedings: International Conference on Acoustics, Speech and Signal Processing (ICASSP), IEEE, vol. 5, pp. V-125-V-128, May 2006.
3. A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, M. Soijacic, "Wireless Power Transfer via Strongly Coupled Magnetic Resonances", Massachusetts Institute of Technology, 2007 Science, Vol. 317. no. 5834, pp. 83— 86, 2007.
4. Tesla's Tower of Power. Information available at the following link, http://www.damninteresting.com/teslas-tower-of-power/
5. Michael Catrysse, Bart Hermans, Robert Puers, "An Inductive Power System with integrated bi-directional Data-transmission", Proceedings: The 17th European Conference on Solid-State Transducers, vol. 115, pp. 221-229, September 2004.
6. Benjamin L. Cannon, James F. Hoburg, Dabiel D. Stancill, Seth Copen Goldstein, Magnetic Resonant Coupling as a Potential Means for Wireless Power Transfer to Multiple Small Receivers, IEEE Transactions on Power Electronics, Vol. 24, No.7, July 2009

7. A.C.M de Queiroz, “Mutual Inductance and Inductance Calculations by Maxwell’s Method”, EE/COPPE , Universidade Federal do Rio de Janerio, Brazil
8. Ghazi Ben Hmida, Hamadi Ghairani and Mounir Samet, “Design of a Wireless power and Data Transmission Circuits for Implantable Biomicrosystem”, Biotechnology, Vol 6, pp. 153-164, 2007.
9. Michael W. Baker, Rahul Sarpeshkar, “Feedback Analysis and Design of RF Power Links for Low-Power Bionic Systems”, IEEE Transactions on Biomedical Circuits and Systems, vol. 1, pp: 28- 38, March 2007.
10. Clemens M. Zierhofer, Erwin S. Hochmair, “High-efficiency coupling-insensitive transcutaneous power and data transmission via an inductive link”, IEEE Transactions on Biomedical Engineering, vol. 37, pp. 716-722, July 1990.
11. Bharatram Satyanarayanan Pundi, “Class-E Power Amplifier Design and Back-Telemetry Communication for Retinal Prosthesis”, MS Thesis, North Carolina State University, Raleigh, North Carolina, 2002.
12. Suresh Atluri, “A Wideband Power Efficient Inductive link for Implantable Biomedical Devices using Multiple Carrier Frequencies”, MS Thesis, North Carolina State University, Raleigh, North Carolina, 2006.
13. Galbraith, Douglas C.; Soma, Mani; White, Robert L., "A Wide-Band Efficient Inductive Transdennal Power and Data Link with Coupling Insensitive Gain,"*Biomedical Engineering, IEEE Transactions on* , vol.BME-34, no.4, pp.265-275, April 1987.

EZEKIEL NNAMERE ANEKE, MIEEE was born in 1984 in Enugu State, Nigeria. He received B.Eng in Electrical and Electronic Engineering from Enugu State University of Science and Technology in 2008; he also received his M.Eng (Power System Option) in Electrical and Electronic Engineering from Enugu State University of Science and Technology in 2014.